

EXPERIMENTAL CRYSTALLIZATION OF YAMATO 980459 M. G. Galenas¹ J. H. Jones², L. R. Danielson³

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Introduction: Currently, only two martian meteorites QUE 94201 (QUE) and Yamato 980459 (Y98) have been experimentally shown to be true melt compositions. Most martian meteorites are instead, cumulates or partial cumulates. We have performed experiments on a Y98 composition to assess whether QUE could be related to Y98 by some fractionation process [1].

Y98 is a basaltic shergottite from the SNC (Shergotty, Nakhla, Chassigny) meteorite group. Y98 is composed of 26% olivine, 48% pyroxene, 25% mesostasis, and no plagioclase [2]. The large size of the olivine megacrysts and absence of plagioclase suggest that the parental melt which formed this meteorite had begun cooling slowly until some mechanism, such as magma ascent, caused rapid cooling [3]. Y98's olivines have the highest Mg content of all the shergottites suggesting that it is the most primitive [4]. Y98 has been determined to be a melt composition by comparing the composition of experimental liquidus olivines with the composition of the cores of Y98 olivines [4]. The liquidus of Y98 is predicted by MELTS [5] and by experimentation [6] to be ~1450°C. Analyses of Y98 show it to be very depleted in LREEs and it has similar depleted patterns as other shergottites such as QUE [7].

Another shergottite, QUE, has a REE pattern similar to Y98. QUE also represents a liquid composition, again by comparing the compositions of natural and experimental liquidus phases [8]. QUE is composed of 44% pyroxene, 46% plagioclase, 2% opaques, 4% phosphates, and 4% mesostasis [9]. Even though QUE contains primitive isotopic characteristics [10], it has evolved characteristics like low bulk Mg #, high incompatible element concentrations in the whole rock, and Fe-rich silicate phases [7,9]. Calculations using the MELTS program have predicted that crystallization of Y98 can yield a composition close to QUE's at 1170°C [1]. The model assumed closed-system-fractional crystallization at 1 bar pressure and oxygen fugacity of QFM-3.

Experimental Methods: Fractional and equilibrium crystallization experiments were performed in Del-Tec furnaces. A rhenium basket was used to contain the sample, a pressed pellet of powdered synthetic Y98. To prevent oxidation of the rhenium wire the

charges were not inserted into the furnace until reducing conditions were reached. Oxygen fugacity of natural Y98 has been estimated to have been about IW+1 [11], and we controlled our experiments at this f_{O_2} using CO/CO₂ gas mixing.

Temperature of the experiments ranged from 1170-1450°C. Fractional crystallization experiments started above the liquidus at 1460°C and descended in temperature at a rate of 2.5°C/hr to temperatures near 1170°C. Equilibrium crystallization charges were taken above the liquidus, to approximately 1460°C, and rapidly dropped down to the set point. There is one exception to this procedure, experiment Y98M-4B, which was inserted into the furnace at 1170°C. Duration of the equilibrium crystallization experiments varied due to length of time required to approach equilibrium. The experiments were water quenched.

Analytical Methods: The Cameca SX100 at NASA JSC was used to determine composition of silicate crystalline and glass phases. A 1-micron focused beam with a current of 10 nA and an accelerating voltage of 15 kV was used for both calibration and analyses.

Results: Olivine was the primary silicate phase at temperatures above 1250°C. At 1250°C low calcium pyroxene appeared. The exact temperature at which pyroxene crystallization begins was not determined but, but MELTS modeling suggests that it is 1320°C [10]. Optical examination suggests that minor pyroxene is present at 1350°C, but this has not been confirmed by electron-probe analysis. Chromites were also found in every run, their size was on the order of several microns at most.

To assess if the experiments approached equilibrium K_D , the distribution coefficient, was calculated for the static "equilibrium" charges. K_D values for olivines ranged from 0.322 to 0.345 and pyroxenes ranged from 0.298 to 0.339. These values are internally consistent with each other and phases were homogeneous (in equilibrium runs). This is also consistent with values from [11] which confirm the reproducibility of the conditions.

Figure 1 shows that QUE's bulk composition lies on a continuum of Y98 crystallization experiments. Dynamic cooling experiments are more representative of QUE mineralogy and composition. Y98M-12,

whose final temperature was 1200°C, is closest in composition to the QUE bulk composition. Major elements were within 7%. (Table 1). However, the minor elements were often rather different from QUE. For example, QUE had more than 7 times the amount of phosphorus than Y98M-12 contained. Details for other elements can be found in Table 1.

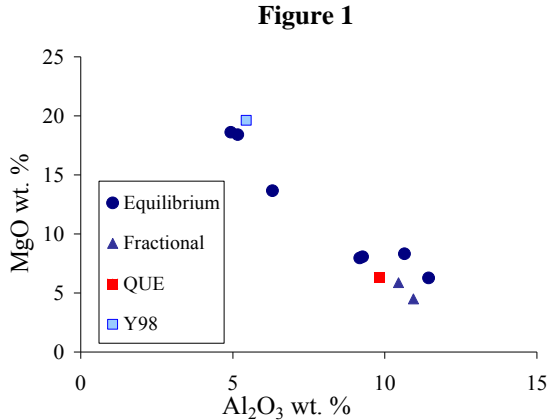


Figure 1: Graph showing the decreasing MgO content with increasing Al₂O₃ content (decreasing temperature). Most MgO rich points are representative of the highest temperatures.

Table 1

	Y98	M12	QUE	Δ QUE
Na ₂ O	0.80	0.51	1.39	-63.42
MgO	18.10	5.88	6.30	-6.67
SiO ₂	49.40	48.77	48.00	1.61
Al ₂ O ₃	6.00	10.45	9.82	6.42
P ₂ O ₅	0.31	0.41	3.09	-86.77
K ₂ O	0.02	0.01	0.04	-75.00
CaO	7.20	11.24	11.48	-2.11
TiO ₂	0.48	1.05	1.98	-46.85
Cr ₂ O ₃	0.71	0.14	0.10	34.65
MnO	0.43	0.50	0.47	6.43
FeO	15.80	19.66	19.16	2.60
Total	99.25	98.62	101.83	

Table 1: Major element compositions of Y98 bulk, M12, and QUE bulk. QUE and Y98 bulk compositions were taken from [12] and [13] respectively. Phosphorus was not analyzed in [12], an average of [14] and [15] values was used to estimate P₂O₅ content in QUE, raising the wt% oxides total for QUE from 98.64 to over 100%. The ΔQUE is the percent deviation of M12 from QUE.

Discussion: The MELTS calculation of [1] of a QUE composition being derived from a Y98 parent has not been confirmed by experimentation. While the major elements are in agreement to within 7%, the

minor elements do not agree. For example, phosphorus is off by almost 90%. Phosphorous and titanium overabundance in the QUE bulk rock are attributed by [1] to the accumulation of phosphates and illmenite. This suggestion is not sufficient because QUE is considered to be a melt composition not a cumulate. Further, the P/Ti ratio of QUE is similar to that of other shergottites. Sodium is somewhat volatile and some is lost during high temperature experimentation and analysis, however the underestimation is significant enough that it is doubtful that it can be attributed only to volatile loss. Y98M-12, the run that contains glass with the most similar composition as the bulk QUE, was also run at a significantly higher temperature, 1200°C than QUE's liquidus [8].

Conclusions: It is unlikely that Y98 is the parental melt for QUE based on the results of this study. However, fractional crystallization of a Y98 composition does produce liquids whose major element compositions are "QUE-like." Because of this and the similarities in initial isotopic compositions between Y98 and QUE [10], we suggest that the QUE parent magma could have been produced from a "Y98-like" source region, but at a lower degree of partial melting than Y98. This plus later, low-pressure fractionation might be sufficient to explain the high incompatible element abundances in QUE relative to fractionated Y98 liquids [1].

References: [1] Symes et al. (2006) *Lunar Planet. Sci. XXVII* abs. 2043. [2] Mikouchi, T. et al. (2003) International Symposium. *Evolution of Solar System: A New Perspective from Antarctic Meteorites*, 82-83. [3] Lenz, R. et al. (2005) *Lunar Planet. Sci. XXXV* abs. 1623. [4] McKay, G. et al. (2004) *Lunar Planet. Sci. XXXV* abs. #2154. [5] Ghiorso, M., and Sack, R. (1995) *Contrib. Mineral. Petrol.* 119, 197-212. [6] Dalton, H. et al. (2005) *Lunar Planet Sci. XXXVI* abs. 2142. [7] Dreibus et al. (1996) *MAPS*, 31 A39-40. [8] McKay G.A. et al. (2002) *Lunar Planet Sci. XXXIII* abs. 2051. [9] McSween et al. (1996) *Geochim. Cosmochim. Acta*, 60, 4563-4569. [10] Borg et al. (1997) *Geochim. Cosmochim. Acta* 61, 4915. [11] Herd C. et al. (2002) *Geochim. Cosmochim. Acta* 66, 2025-2036. [11] Jones, J. (1995) *Ahrens, T.J. (ed.), Rock Physics and Phase Relations, A Handbook of Physical Constants, AGU Reference Shelf 3, AGU, Washington.* 73-104. [12] Warren, P. and Kallemeyn, G. (1997) *Ant. Met. Research* 10, 61-81. [13] Greshake A. (2004) *Geochim. Cosmochim. Acta* 68 2359-2377. [14] Kring, D. et al. (1996) *Lunar Planet Sci. XXVII* 705-706. [15] Mikouchi, T. et al. (1996) *Lunar Planet. Sci. XXVII*, 879-880.